Design and Evaluation of an Efficient Seamless Communication Technique for Mobile Wireless Networks

Ihn-Han Bae† and Yoon-Jeong Kim††

ABSTRACT

This paper presents an efficient method to provide seamless communication in mobile wireless networks. The goal of seamless communication is to provide disruption free service to a mobile user. A disruption in service could occur due to active handoffs. There are many user applications that do not require a total guarantee for disruption free service but would also not tolerate very frequent disruptions. This paper proposes an extended staggered multicast that provides a probabilistic guarantee for disruption free service. The proposed multicast forecasts the direction and velocity for a mobile host. It is possible that data packets for a mobile host are multicasted to not all neighbor cells but a part of neighbor cells those the mobile host will be handoff potentially on the basis of these information. Therefore, the extended staggered multicast significantly reduces the static network bandwidth usage also provides a probabilistic guarantee for disruption free service.

이동 무선망을 위한 효율적인 무단절 통신 기법의 설계 및 평가

배인한† · 김윤정††

요 약

본 논문에서는 이동 무선망에서 무단절 통신을 제공하는 효율적인 방법을 제안한다. 무단절 통신의 목표는 이동 사용자에게 단절 자유 서비스를 제공하는데 있다. 서비스의 단절은 활동적인 핸드오프에 의해 발생된다. 이동 무선망에는 단절 자유 서비스에 대한 완전 보장을 요구하지 않으나 아주 빈번한 단절을 허용치 않는 많은 사용자 응용들이 있다. 본 논문에서는 단절 자유 서비스에 대한 확률적 보장을 제공하는 확장된 지연 멀티캐스트를 제안한다. 제안하는 멀티캐스트에서는 이동 호스트의 속도와 방향을 예측하고, 그러한 정보를 기초로 모든 이웃 셀이 아닌 그 이동 호스트가 핸드오프 할 가능성이 있는 일부 이웃 셀에게만 지연 멀티캐스트가 가능하다. 따라서 확장된 지연 멀티캐스트 방법은 정적 네트워크 대역폭 사용을 상당히 감소시키고 또한 단절 자유 서비스에 대한 확률적 보장을 제공한다.

1. Introduction

Mobile computing refers to an emerging new computing environment incorporating both wireless and wired high-speed networking technologies. In the near future, it is expected that millions of users will have access to a wide variety of services that will be made available over high-speed networks.

When a *mobile host* (MH) is engaged in a call or data transfer, it will frequently move out of the coverage area of the mobile support stations it is communicating with, and unless the call is passed

† 정회원, 대구가톨릭대학교 컴퓨터정보통신공학부 교수
†† 준회원, 대구가톨릭대학교 대학원 전산통계학과 전산전공

on to another cell, it will be lost. Thus, the task of forwarding data between the static network and the mobile user must be transferred to the new cell's *mobile support station* (MSS). This process, known as handoff, is transparent to the mobile user. Handoff helps to maintain an end-to-end connectivity in the dynamically reconfigured network topology.

To illustrate some of the unique features of the mobile computing environment, consider a situation where several mobile users have opened high-bandwidth data connections. When these data connections are set up, the network ensures that the users receive some guaranteed quality of service (such as delay and jitter bounds, minimum and maximum bandwidth requirements and maximum loss bound, etc.). Since these users are all mobile, it is possible that many of them could move into the same cell. In such a situation, it is very likely that the available bandwidth of the cell will be exceeded resulting in the original quality of service parameters being violated. This situation does not arise in high-speed networks because users are not mobile during the life-time of connection[2].

Mobility of users is attended with several network management problems. These problems generally classify into mobility and connection managements. This paper deals with the important problem that is related with connection management in mobile wireless networks. The problem is the seamless communication that provides disruption free service to mobile users. Providing disruption free service is stronger requirement than mere connection-oriented services. In addition to maintaining the connection, the network will need to ensure that the delay experienced by the data packets over the network is less than a fixed time called the deadlines. The deadline is in turn determined by the *quality of service* (QoS) required by the users. The goal to seamless communication is to provide disruption free service to a mobile user. A disruption in service could occur due to active handoffs. This is because traditional protocols require the old MSS to forward data packets to the new MSS. Thus, every time a mobile user moves into a new cell during the connection (active handoff), the user will see a break in service while the data gets forwarded to it from the old MSS via the new MSS. The number of disruptions seen by the user will depend on the number of handoffs incurred during the lifetime of the connection. The number of handoffs in turn depends on the mobility pattern of the user[1,2].

This paper proposes an extended staggered multicast that provides probabilistic seamless communication for disruption free service. The proposed multicast forecasts the cell latency of a mobile host and the neighboring cells those the mobile host will be handoff potentially by using the MH's velocity and direction, and performs staggered multicast to only the forecasted neighboring cells according to probabilistic QoS. The extended staggered multicast significantly reduces the static network bandwidth usage also provides a probabilistic guarantee for disruption free service.

The remainder of this paper is organized as follows. Section 2 describes related works for seamless communication in mobile wireless networks. Section 3 proposes an extended staggered multicast considering mobility prediction that provides a probabilistic guarantee for disruption free service. Section 4 evaluates the performance of the proposed multicast through a simulation study. Finally, concluding remarks are presented in section 5.

2. Related Work

Previous works for seamless communication that guarantees disruption free service are as follows. Singh in [1] proposed a multicast based solution for disruption free service. In this approach, the data packets for an MH are multicasted to the MSSs of the neighboring cells so that when the MH moves to a new cell, there are data packets

already waiting for it and thus, there is no break in service. It is evident, however, that this approach is not cost effective. As the number of users in the network increases, the amount of network bandwidth used up by the multicast connections is going to be prohibitively high.

Singh's another research in [2] identified two additional QoS parameters those are essential to specifying grades of service for mobile users. These parameters are loss profiles and probability of seamless communication, where loss profile specifies a preferred way in which data can be discarded in the event that bandwidth requirements within a cell exceed the available bandwidth. Depending on the type of application, a mobile user may require a probability of seamless communication. Based on user requirements, the composition of a group and the time at which the cells in the group begin predictive buffering are determined. In this approach, the data packets for a mobile host are multicasted to all the MSSs of neighboring cells, so that network bandwidth is wasted because all the MSSs of neighboring cells buffer data packets from the time that begins predictive buffering.

Bakshi et al. in [3] proposed a staggered multicast approach that avoids unnecessary multicast to all the MSSs of neighboring cells during the connection by using cell latency. The cell latency will solely depend on the mobility model of the host. Two mobility models: *pessimistic* and *optimistic* were proposed to compute the cell latency. The performance of the staggered multicast was evaluated by the overhead of network bandwidth. In this approach, the time at which data packets are multicasted to all the MSSs of neighboring cells is delayed, but the data packets are multicasted to all the MSSs of neighboring cells in the same manner with [1,2].

Aljadhai et al. in [8] proposed a framework to support predictive timed-QoS guarantees in wireless environments. The main components of this framework include a service model for QoS guarantees, a path predictability model, and a call admission control scheme. The framework determines the mobile's *most likely cluster* (MLC) and estimates the mobile's earliest arrival time, latest arrival time and latest departure time for the MLC. These estimates are then used by the call admission control to determine the feasibility of admitting a call by verifying that enough resources are available in each of the MLC cells.

Yoon-Jeong Kim and Ihn-Han Bae in [10] proposed a seamless communication method, where the mobility direction of a mobile host is computed by exponential averaging, the handoff probability to each cell is computed by the numerical integration of probability density function. Because data packets multicast to a part of neighboring cells, this method provided better performance than other methods.

We propose an extended staggered multicast that provides probabilistic seamless communication for disruption free service. Based on the location information for an MH in MSS, the extended staggered multicast estimates the MH's velocity and direction, and forecasts the cell latency of the MH and the neighboring cells those the MH will be handoff potentially. So, the data packets for the MH are multicasted to the only MSSs of the forecasted neighboring cells, after a stagger time.

3. Probabilistic Seamless Communication Approach

In this paper, we propose the extended staggered multicast that data packets are multicasted to only the neighboring cells which a mobile host will be handoff potentially, after a stagger time. Each MSS of cells maintains the location information for local MHs (Fig. 1). The location information such as the MH's velocity and direction is obtained through *deregister* and *register* messages those are exchanged between old MSS and new MSS, when

the MH is handoff.

mh_id	mss_id	reg_time	velocity	angle

- mh_id : MH identifier
- mss_id : MSS identifier
- reg_time: the system time that the mobile host is registered at the MSS
- velocity : the average velocity of the mobile host
- angle : the average mobility angle of the mobile host

Fig. 1. The location information for MH in MSS.

3.1 Mobility Direction

The mobility direction of an MH is estimated by the history of recent handoffs, where the history represents the handoff from any cell among six neighboring cells to the existing cell (Fig. 2). The forecasted mobility angle of the MH is computed by *adaptive-response-rate single exponential smoothing* (ARRSES) [11]. The basic equation for forecasting with the method of ARRSES is as follow:

$$F_{t+1} = \alpha_t Y_t + (1-\alpha_t)F_t \quad .... \quad (1)$$

$$\text{where} \quad \alpha_t = \left| \frac{A_t}{M_t} \right|$$

$$A_t = \beta E_t + (1-\beta)A_{t-1}$$

$$M_t = \beta |E_t| + (1-\beta)M_{t-1}$$

$$E_t = Y_t - F_t$$
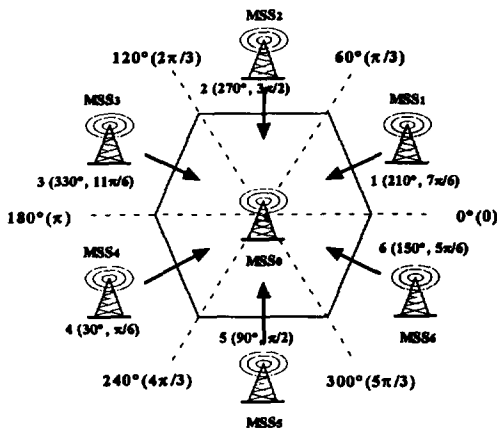
Fig. 2. The average angle that the MH enters according to mobile direction.

In the above equation (1), Y_t represents the average angle which enters from the last cell to the existing cell, F_t represents the forecasted mobility angle of the host at the last MSS, and β is a parameter between 0 and 1.

3.2 Mobility Velocity

When a mobile host crosses cell boundary, the mobility direction of the mobile host is indicated by the angle ϕ between the direction of the mobile host and the direction from the mobile host to the center of a cell as shown in Fig. 3. If we assume that the mobile host moves with any direction with equal probability, the random variable ϕ has *probability density function* (pdf) as

$$f_\phi(\phi) = \begin{cases} \frac{1}{\pi}, & -\frac{\pi}{2} \le \phi \le \frac{\pi}{2} \\ 0, & elsewhere \end{cases} .$$
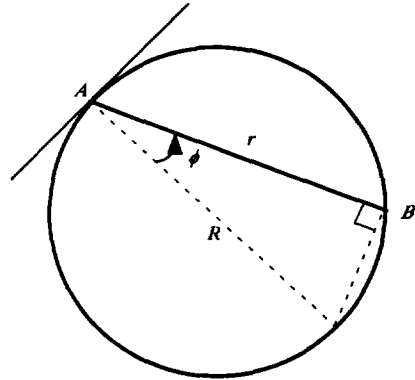
Fig. 3. The distance from point A on cell boundary to point B on cell boundary.

The distance r is computed as follows:

$$r = R\cos\phi$$

where R represents the hexagonal cell radius. If we assume that all the radiuses of cells are same, the average crossing distance d is computed as follow:

$$d = \frac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} R\cos\, d\phi = \frac{2R}{\pi}$$

Let t_{c-1} be the system time of last registration for the mobile host, and t_c be the system time of current registration for the mobile host. The velocity of the mobile host is estimated by equation (2).

$$v = \frac{d}{(t_c - t_{c-1})} \quad \cdots\cdots\cdots \quad (2)$$

3.3 Extended Staggered Multicast

To design our extended staggered multicast, the cell latency and the probability that a mobile host will be handoff from the existing cell to each of neighboring cells are necessary. Accordingly, we first compute the MH's cell latency and handoff probability for each of neighboring cells. Based on the computed these information, we design the extended staggered multicast which provides a probabilistic guarantee for disruption free service.

• Handoff Cell Prediction

Consider an MH currently residing at cell i coming from cell m, and let j, $j = 1, 2, \ldots$, represent a set of adjacent cells to cell i. Each cell j is situated at an angle ω_{ij} from the horizontal axis passing by the center of cell i, as depicted in Fig. 4. Furthermore, define the *directional path* from i to j as the direct path from the center of cell i to the center of cell j.
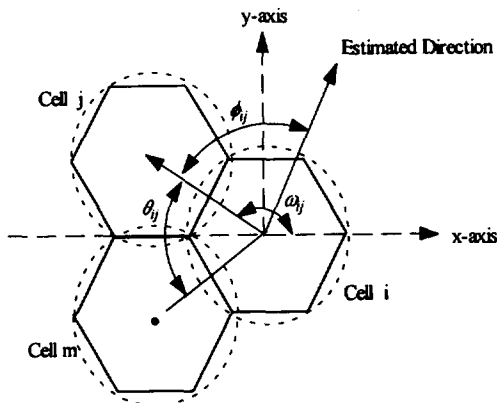
Fig. 4. Parameters used to calculate the directional probability.

Based on the directional path, the *directionality*, D_{ij}, for a given cell j can be expressed as:

$$D_{ij} = \frac{\delta\theta_{ij} + (1-\delta)(\theta_{ij-1} + \theta_{ij+1})/2}{\delta\phi_{ij} + (1-\delta)(\phi_{ij-1} + \phi_{ij+1})/2} \quad \cdots\cdots\cdots \quad (3)$$

where ϕ_{ij} is an integer representing the deviation angle between the straight path to destination and the directional path from i to j, while θ_{ij} represents the angle between the directional path from m to i and the directional path from i to j, and δ $(0 < \delta < 1)$ is a parameter for the directionality.

Based on its directionality D_{ij}, the directional probability, $P_{i\to j}$, of cell j being visited next by a mobile unit currently at cell i can be expressed as follows:

$$P_{i \to j} = \frac{D_{ij}}{\sum_k D_{ik}} \quad \cdots\cdots\cdots \quad (4)$$

where k represents a number of adjacent cells to cell i.

• Cell Latency

How long is the mobile host going to remain in the same cell, this period is called cell latency. The average cell latency T_h is computed by equation (5).

$$T_h = \frac{d}{v} = \frac{2R/\pi}{v} = \frac{2}{\pi} \cdot \frac{R}{v} \quad \cdots\cdots\cdots \quad (5)$$

Accordingly, the mobile host resides in the cell during average T_h time units.

• Probabilistic QoS Guarantee

The extended staggered multicast provides two types of QoS: total guarantee, probabilistic guarantee for disruption free service. The total guarantee cannot tolerate disruptions during the time of connection. On the other hand, the probabilistic guarantee tolerates a probabilistic guarantee for disruption free service.

Let P_{d_i} be the probability of disruption during the i-th handoff, t_s be the stagger time that can be safely introduced before initiating a multicast, t_i be the cell latency before the i-th handoff, and t_{m_i} be the time spent in multicast mode before the

i-th handoff. Also, let nc_{m_i} be the set of the neighboring cells that data packets are multicasted before the i-th handoff.

A disruption occurs when a mobile host initiates a handoff before multicast has been initiated or the cell c_i which an MH moves into by the i-th handoff does not exists in nc_{m_i}. Then the probability of disruption during the i-th handoff can be given as:

$$P_{d_i} = \Pr[t_s > t_i \ or \ c_i \notin nc_{m_i}]$$

If the number of handoffs occurring over the length of the connection time T_c is N_h, the average probability of disruption during a handoff, P_d is determined as:

$$P_d = \frac{1}{N_h}\sum_{i=1}^{N_h} P_{d_i}$$

The value of P_d can now be used as a measure of the QoS. Then, total guarantee is P_d = 0, and probabilistic guarantee is $P_d > 0$.

Fig. 5 presents an example showing the times of handoffs and multicast initiations. The times B, D, F and H represent the time at which handoff take place. The times A, C, E and G represent the times at which multicast is initiated. The cell latencies for Fig. 5 are $t_1 = t_s + t_{m1}$, $t_2 = t_s + t_{m2}$, and so on. For total guarantee, the following should hold.

$$\forall i, \ 1 \le i \le N_h, \ t_s < t_i$$

i.e., for all handoffs a multicast is initiated within the associated cell latency interval.

Fig. 6 shows the times of handoffs and multicast initiations in the multicast scheme that provides a probabilistic guarantee. The times B, D, E and G represent the time at which handoff takes place.
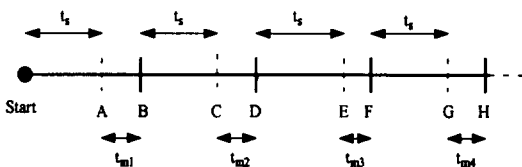
Fig. 5. Total Guarantee.
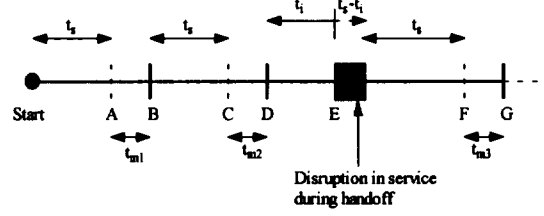
Fig. 6. Probabilistic Guarantee.

The times A, C and F represent the time at which the multicast is initiated. As noticed in the figure, there is a disruption in service during handoff at time E, because, there was no multicast initiated before the handoff. Thus, a disruption occurs during the i-th handoff when the stagger time t_s is greater than the cell latency time t_i.

In the extended staggered multicast, when a call is established between an MH and an MSS, a probabilistic of disruption free service P_{df} is setting as QoS parameter, where $P_{df} = 1 - P_d$. Then, the multicast and staggered times for the MH are computed as follows respectively:

$$t_{m_i} = P_{df} \times T_h$$

$$t_s = T_h - T_{m_i}$$

The neighboring cells those data packets are multicasted are computed as follows. First, $P_{i \to j}$ (j=1,...,6) are sorted in nonincreasing order, then the cell k is included in NC_{mi} until $\sum_{k=1}^{l} P_{i \to k} \ge P_{df}$. In the extended staggered multicast, after the mobile host enters the existing cell, data packets are multicasted to the l neighboring cells in NC_{mi} after the staggered time t_s.

Fig. 7 and Fig. 8 show the difference between the existing multicast and the extended staggered multicast. In the case of total guarantee, the extended staggered multicast is equal to the existing multicast. But, in the case of probabilistic guarantee, the extended staggered multicast saves more static network bandwidth than the multicast and the staggered multicast.
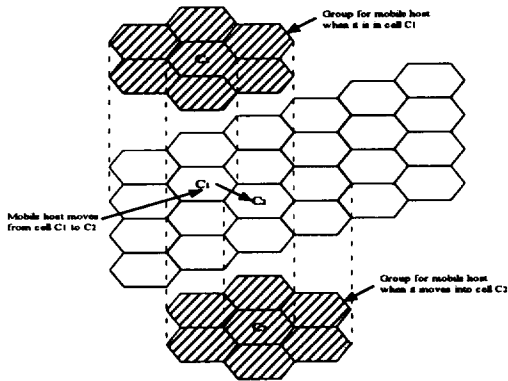
Fig. 7. Existing multicast.
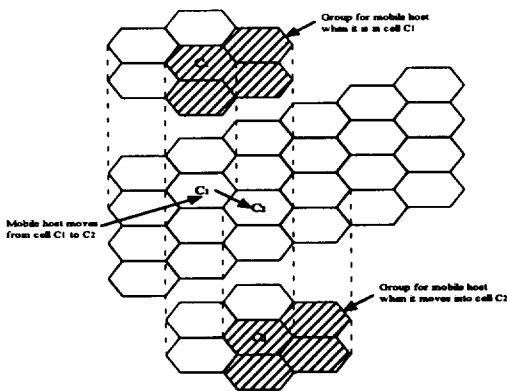
Fig. 8. Extended staggered multicast.

4. Performance Evaluation

In this paper, we evaluate the performance of the extended staggered multicast through a simulation study. The simulation parameters are shown in Table 1.

Table 1. Simulation parameters

Parameter	Data value
Mobile direction (Y)	$(\pi, (\frac{\pi}{3})^2)$
Mobile velocity (v)	250±50/min (random)
Forecasting parameter (β)	0.2
Directionality parameter (δ)	0.5
Probabilistic of disruption free service (P_{df})	0.7
Cell radius (R)	100 m

Let the mobile network is based on hexagonal cell model that one neighboring cell exists at every $\pi/3$ in $0 \le \theta < 2\pi$ (show Fig. 2). The number of neighboring cells on a cell, nc is 6, where the neighboring cell which is adjacent to $0 \le \theta < \pi/3$ is called the 1-st neighboring cell, the neighboring cell which is adjacent to $\pi/3 \le \theta < 2\pi/3$ is called the 2-nd neighboring cell, and so on.

The performance of the extended staggered multicast scheme is evaluated by the bandwidth overhead of multicast scheme given as equation (6).

$$Overhead = \frac{T_m}{T_c} \times \frac{NC_m}{NC} \times 100 \quad .... \quad (6)$$

where $T_m = \sum_{i=1}^{N_h} t_{m_i}$, $NC = 6 \times N_h$ and $NC_m = \sum_{i=1}^{N_h} nc_{m_i}$.

In the simulation environments such as Table 1, the cell latency of a mobile host that is computed by equation (5) is 15.3 seconds, the staggered time is 4.6 seconds, and the multicast time is 10.7 seconds. The probability that the mobile host will be handoff to a neighboring cell is computed by equation (3) and equation (4). In the simulation, we first occur 100 times of handoff, then simulation results are analyzed and evaluated by 50 times of handoff from the 51-th handoff to the 100-th handoff. Table 2 shows the simulation result of the extended staggered multicast during 10 times of handoff from the 51-th handoff to the 60-th handoff. We know that the probability of disruption free service is 0.8 that is larger than P_{df}, because 8 times of handoff are guaranteed among 10 times of handoff. Therefore, the extended staggered multicast provides the correct probabilistic guarantee for disruption free service.

Fig. 9 shows the MH's actual and forecasted paths and the neighboring multicast cells during 10 times of handoff from Table 2, respectively.

Fig. 10 shows the performance of multicast schemes according to QoS probabilistic. In the case of total guarantee, it is known that the performance of the *extended staggered multicast* (XSM) is the

Table 2. The simulation results of the extended staggered multicast for handoffs
(G: Guarantee, NG: Non-guarantee)

handoff no.	51	52	53	54	55	56	57	58	59	60
actual mobility angle	120°	154°	210°	163°	143°	127°	161°	242°	136°	173°
Forecasted mobility angle	189°	166°	161°	164°	163°	159°	148°	150°	178°	175°
Mobility velocity	222m	257m	296m	263m	200m	277m	295m	290m	204m	280m
Cell latency	3.8sec	19.4sec	11.3sec	15.56sec	28.2sec	20.8sec	16.9sec	3.2sec	8.1sec	17.1sec
Actual handoff cell	3	3	4	3	3	3	3	5	3	3
Forecasted handoff cell	4	3	3	3	3	3	3	3	3	3
the set of neighboring cells for multicast	{3,4,2}	{3,4,5}	{3,2,4}	{3,4,2}	{3,4,5}	{3,4,2}	{3,2}	{3,2}	{3,4,2}	{4,3,5}
Disruption free service	NG	G	G	G	G	G	G	NG	G	G
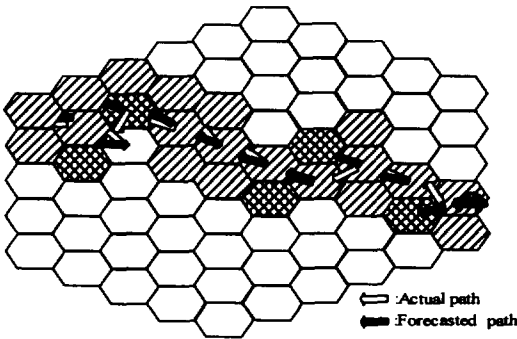
Fig. 9. The actual and forecasted paths for the MH.
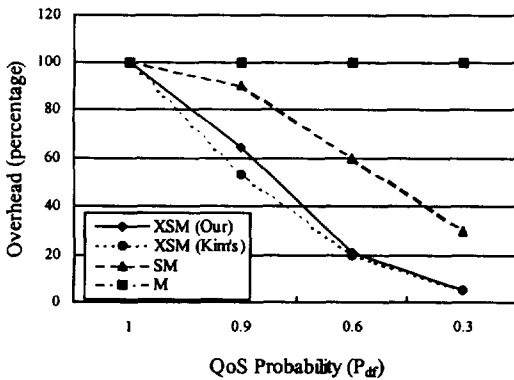
Fig. 10. The multicast overheads for QoS probability

equal to that of the *multicast* (M) and that of the *staggered multicast* (SM). However, in the case of probabilistic guarantee, the performance of XSM is better than that of M and that of SM. We show that our performance and Kim's [10] performance are much the same, but Kim's XSM has the following drawbacks. First, the accurate mobility direction of a mobile host can't be forecasted by exponential averaging. Second, the computation of handoff probability has much complexity and includes some errors because it is computed the numerical integration, Simpson's rule [12].

Fig. 11 shows the comparison of the number of guarantees between our method and Kim's method, where the number of guarantees is computed by the number of handoffs that provide disruption free service during 50 times of handoffs from the 51-th handoff to the 100-th handoff. In the case that probability of disruption free service is 0.7, our method guarantees disruption free service in 34 times of handoffs (P_{df}=0.68), but Kim's method
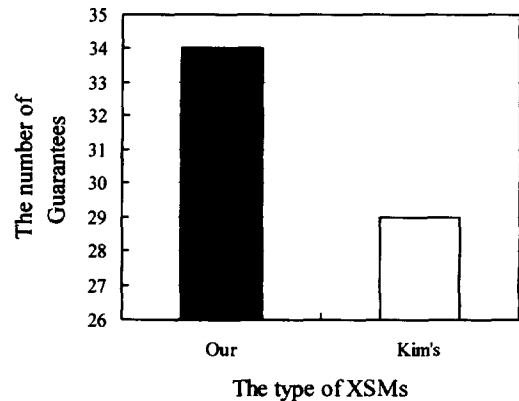
Fig. 11. The performance comparison between our method and Kim's method (P_{df}=0.7).

guarantees only disruption free service in 29 times of handoffs (P_{df}=0.58). Accordingly, we know that the ARRSES of our method forecasts more accurate mobility direction of mobile hosts than the exponential averaging of Kim's method. Because the P_{df} of our method is closer to the predefined QoS value for P_{df} than Kim's method, our method provides better QoS than Kim's method for the same probability of disruption free service.

5. Conclusion

There are the various applications that provide the quality of service required by the users in mobile networks. The number of cells may become insufficient to provide the required quality of service because of the increment of service requests and the mobility of users. Cell splitting can then be used to increase the traffic handled in an area without increasing the bandwidth of the system. The reduction in the cell size causes an increase in the number of handoffs, thereby increasing the signaling traffic due to the handoff protocol messages. In addition, handoff also causes a disruption in service if it is not done in a fast efficient manner.

In this paper, we propose the extended staggered multicast that provides a probabilistic guarantee for disruption free service despite handoff during an active connection. The extended staggered multicast estimates the velocity and direction for a mobile host and forecasts the cell latency, the stagger and multicast times, the probability that the MH will be handoff to each of neighboring cells, respectively. Then, according to the required QoS for a user, data packets are multicasted to the forecasted neighboring cells that the MH will be handoff potentially, after the stagger time. From the simulation results, the performance of the extended staggered multicast is better than that of the multicast and that of the staggered multicast. Also, we show that our method provides better QoS than Kim's method, the same type of extended staggered multicast. Therefore, the extended staggered multicast significantly reduces the static network bandwidth usage also provides a probabilistic guarantee for disruption free service.

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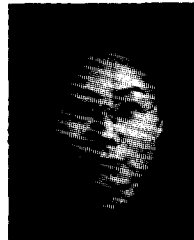
배 인 한

1984년 경남대학교 전자계산학과 졸업(학사)
1986년 중앙대학교 대학원 전자계산학과 졸업(석사)
1990년 중앙대학교 대학원 전자계산학과 졸업(박사)
1996년~1997년 Dept. of Computer and Information Science, The Ohio State University (Postdoc)
1989년~현재 대구가톨릭대학교 컴퓨터정보통신공학부 부교수
2000년~현재 대구가톨릭대학교 전자계산소장
관심분야 : 인터넷, 이동무선망, 멀티미디어 시스템, 분산 시스템 등

김 윤 정

1993년 효성여자대학교 전자계산학과 졸업(학사)
1995년 효성여자대학교 대학원 전산통계학과 전산전공 졸업 (석사)
1997년~현재 대구가톨릭대학교 대학원 전산통계학과 전산전공 (박사과정)
관심분야 : 인터넷, 이동무선망, 멀티미디어 시스템, 분산 시스템 등